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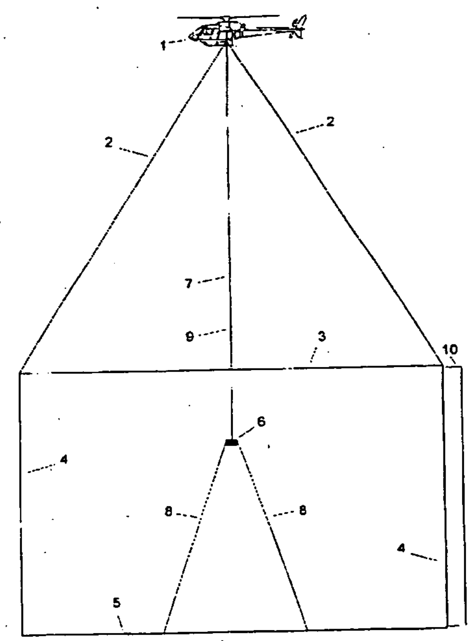
(54) **APPAREIL POUR RECONNAISSANCE ELECTROMAGNETIQUE AEROPORTEE**

(54) **APPARATUS FOR AIRBORNE ELECTROMAGNETIC SURVEYING**



(57) Dans les systèmes aéroportés qui émettent et captent des champs électromagnétiques pour l'exploration géophysique, il faut monter les antennes émettrices sur un aéronef ou sur une structure rigide fixée à un aéronef ou remorquée sous celui-ci. Dans chaque cas, l'aire de l'antenne émettrice est limitée par les dimensions de la structure rigide, ce qui limite le moment dipolaire de l'antenne et, par conséquent, l'intensité du signal capté par le système. Cette limitation est particulièrement prononcée dans les systèmes utilisant des antennes montées sur des structures remorquées. La présente invention est un système utilisant une antenne émettrice aéroportée à aire variable. Avant l'envol et durant l'atterrissage, l'antenne peut être ployée pour des raisons de sécurité et des raisons pratiques. En vol, elle est déployée et offre une aire stable de grandes dimensions, ce qui procure une grande sensibilité de réponse aux éléments conducteurs enfouis dans la terre.

(57) In systems carried by aircraft that transmit and receive electromagnetic fields for geophysical exploration, it is known to mount transmitting antennae on an aircraft or other rigid structure attached to or towed beneath an aircraft. In every case, the area of the transmitting antenna is limited by the dimensions of the rigid structure, which limits the dipole-moment of the antenna and thus the strength of the signal received by the system. This limitation is particularly severe for systems using antennae in towed structures. The present invention consists of a system that incorporates an airborne electromagnetic transmitting antenna with flexible area. Before take-off and during landing, the area of the antenna may be collapsed for safety and convenience. In flight, the antenna assumes a large and stable area, which induces strong electromagnetic responses from conductive features in the earth.

ABSTRACT

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In systems carried by aircraft that transmit and receive electromagnetic fields for geophysical exploration, it is known to mount transmitting antennae on an aircraft or other rigid structure attached to or towed beneath an aircraft. In every case, the area of the transmitting antenna is limited by the dimensions of the rigid structure, which limits the dipole-moment of the antenna and thus the strength of the signal received by the system. This limitation is particularly severe for systems using antennae in towed structures. The present invention consists of a system that incorporates an airborne electromagnetic transmitting antenna with flexible area. Before take-off and during landing, the area of the antenna may be collapsed for safety and convenience. In flight, the antenna assumes a large and stable area, which induces strong electromagnetic responses from conductive features in the earth.

This invention relates to an apparatus, or airborne electromagnetic system, for geophysical mapping, sounding or exploration. The system incorporates a collapsible transmitting antenna. The antenna is made up of rigid portions that maintain its approximate area and shape during flight, and flexible portions that permit the antenna to collapse for take-off, landing, storage and transportation. When connected to the rest of an airborne electromagnetic system, the transmitting antenna transmits a repetitive magnetic field, or primary field, which induces electrical current in the earth. The current in the earth generates a secondary magnetic field which, in turn, induces currents in the receiving antennae of the system.

At present, all airborne electromagnetic systems use one of two types of transmitting antennae, both of which have been in use for more than 40 years. The most effective type of antenna consists of several turns of wire looped horizontally around an aircraft (cf. Canadian Patent 564,361, Canadian Patent 1,168,308), and fixed at several points to the aircraft. The abbreviation FL, for Fixed Loop, is used in the following discussion for this type of antenna and system with which it is used. For most installations, the area enclosed by a turn of an FL antenna ranges from 180 m^2 to 240 m^2. The area is limited by the length and wingspan of aircraft that can be used economically for surveys.

For FL systems, the transmitting loop of several turns of wire is fixed to booms on the nose, wing-tips and tail of a STOL aircraft. Signal-generating means, signal processing means and a winch are mounted in the aircraft. Receiving antennae are housed in a structure called a bird which is towed at the end of a flexible signal-cable about 120 m behind and 60 m below the aircraft. During take-off and landing, the cable is wound on the drum of the winch, so that

the bird is held against the fuselage of the aircraft. Aircraft carrying FL systems are flown at a nominal speed of 200 km/h and ground clearance of 120 m.

To enclose the largest area that can be borne by the aircraft, the turns of wire in an FL antenna are fixed to the nose, wing-tips and tail. As a result, the turns of an FL antenna are approximately horizontal. An antenna of this orientation couples most effectively with horizontal features in the earth. In general, this is disadvantageous with regard to mineral exploration as the horizontal regolith containing, for example, clay, ionic groundwater, or weathered bedrock, is typically more conductive than the underlying bedrock which hosts mineral deposits. Thus, the horizontal FL antenna is most susceptible to electromagnetic masking of the bedrock by the regolith. Furthermore, many mineral deposits, such as massive sulfides in shield-terrain and kimberlite diatremes, tend to be oriented vertically and thus couple minimally with the horizontal FL antenna.

Systems with FL antennae tend to be uneconomic for many of the surveys specified for mining exploration and geological mapping. Installation of such a system in an aircraft is a complex and protracted process. Extensive modifications to the aircraft are required to create air-worthy points of attachment for the antenna, and numerous test-flights and adjustments are needed to identify and eliminate aircraft-related noise from the response of the system. Once installed, FL systems are seldom (if ever) removed and the modified aircraft cannot be used economically for any other purpose. As a result, a large portion of the cost of surveying with FL systems represents fixed investment in a specialized aircraft, and the transportation around the world of the system by the survey aircraft. Fixed investment routinely causes economic difficulty for airborne electromagnetic surveyors, as the demand for such surveys fluctuates

greatly from year-to-year and, in accordance with prices for base-metals, may remain depressed for several consecutive years. Transporting an electromagnetic system by means of the survey aircraft is inefficient, as these aircraft are chosen for their manoeuvrability at slow speed and low altitude, rather than their efficiency at hauling cargo over long distances.

The second type of airborne electromagnetic transmitting antenna in general use is a fixed coil of wire. For a few systems, the coil is mounted on a wing-tip or nose of a fixed-wing aircraft (cf. Canadian Patent 653,286); more commonly, the coil is installed in a fibre-reinforced plastic bird, which is slung beneath a helicopter (cf. Canadian Patent 680,143). The abbreviation FC, for Fixed Coil, is used in the following discussion for this type of antenna and system with which it is used. An FC antenna is a bobbin-wound coil of wire, encased in plastic, that fits within the diameter of the bird, which is typically 0.5 m. To increase transmitted moment, an FC antenna may be wound with several hundred turns, to obtain an effective area of in the order of 50 m^2.

A typical helicopter-borne FC system is slung on a cable 30 m in length from the cargo-hook of a helicopter. The cable tows an assembly that provides aerodynamic stability and suspension for a cylindrical bird that houses the FC transmitting and receiving antennae. Conductors in the cable carry power from signal-generating means in the helicopter to the transmitting antennae, and signal from the receiving antennae to signal-processing means in the helicopter. The bird is flown at a nominal speed of 100 km/h and ground clearance of 30 m. *Ceteris paribus*, lower ground-clearance enables more detailed measurements to be made of stronger electromagnetic responses from the earth. However, the smaller dipole-moment of the FC antenna results in significantly weaker responses from the earth, despite the lower

ground-clearance at which helicopter-borne FC systems are flown. Nevertheless, FC systems are widely used because they can be transported less expensively than FL systems, and used temporarily in locally available helicopters.

The component of an FC system that is most difficult to transport is the bird which is approximately is 8.5 m in length, 0.5 m in diameter, and weighs about 100 kg. Components of this scale can be transported by light trucks with special fittings, or by aircraft that carry cargo longer than the standard 200 inches (5 m). Although such transportation is more economical than transportation by survey aircraft, shipping large and heavy birds remains costly and inconvenient. Indeed, many surveys cannot be performed economically, where they are required for remote areas where there is no infrastructure of roads or airports that service large cargo.

As airborne electromagnetic surveys have been relatively expensive, they have been flown in rather limited areas, as compared to other airborne geophysical surveys such as magnetics or gamma-ray spectrometry. This has retarded the discovery of many ore-deposits which have been found to respond to airborne electromagnetic surveys, subsequent to discovery by slower and, ultimately, more expensive means. A recent example in Canada is the nickel-copper-cobalt discovery at Voisey Bay, NF (cf. The Northern Miner, April 17, 1995, p.3).

The present invention overcomes the small-transmitter disadvantage of FC systems, and the inconvenience of FL systems, by providing an airborne electromagnetic system which incorporates a transmitting antenna which can be expanded to enclose a large area to induce

strong responses from the earth, yet which can be collapsed for ease of take-off, landing, disassembly and shipment.

The transmitting antenna of the system consists of one-or-more turns of wire, slung from the cargo-hook of a helicopter or deployed through ports in the belly of an aircraft. The antenna contains flexible portions to allow the antenna to expand and collapse, and rigid portions to stabilize the shape and area of the expanded antenna. The flexible portions consist of wire and, where necessary, flexible insulation or reinforcement. The rigid portions consist of wire held by supports. Both the flexible and rigid portions of the antenna disassemble into pieces with the dimensions of standard cargo. Devices may be attached to the antenna to support receiving antennae or other components of the airborne system.

Tests of aerodynamic behaviour have been made with scale models of several versions of the antenna. The tests indicate that, without additional aerodynamic devices attached to the antenna, the antenna tends to align itself so that the rigid portions are either perpendicular to or aligned with the flow of air past the antenna; as the direction of air-flow changes, the antenna may spontaneously realign to the alternate position of relative stability. Aerodynamic devices such as stays, vanes and skirts may be attached to the antenna to create a unique alignment of stability; the flexible and rigid portions of the antenna may be designed and arranged for the same purpose. The preferred alignment has the rigid portions aligned with the flow of air (i.e. with the flight path). Aligned thus, the antenna couples optimally with conductive features in the sparsely sampled earth between flight-lines.

The antenna transmits a repetitive magnetic field, arising from a repetitive current supplied to the antenna by signal-generating means of the airborne electromagnetic system. The system draws power from the auxiliary power-supply of the aircraft.

One-or-more receiving antennae are suspended beneath the aircraft, and held 15 m or more from the transmitting antenna by flexible or rigid supports, so that the receiving antennae are not saturated by the primary field of the transmitting antenna.

A preferred embodiment of the invention provides an airborne electromagnetic transmitting antenna consisting of 1 turn of AWG#8 aluminum wire. Flexible portions of the antenna consist of wire, which may insulated and/or reinforced. Rigid portions of the antenna consist of wire supported by fibre-reinforced plastic.

In this embodiment, auxiliary supports are attached to the antenna such that the transmitting antenna takes on the form of a 5-sided polygon, measuring about 58 m in height and up to 36 m in width, yielding an area of about 1500 m^2.

Exemplary embodiments of the invention are illustrated in Figure 1, which depicts a collapsible transmitting antenna and ancillary components slung beneath a helicopter. Signal-generating means, signal-processing means, and ancillary instrumentation similar to those used for standard FL systems (cf. Canadian Patent 662,184) are mounted in a helicopter (1). Flexible portions (2) of the transmitting antenna connect to the signal-generating means and suspend the antenna from the cargo-hook of the helicopter. A support (3) spreads and stabilizes the centre of the antenna. The support is made up of hollow rods made of fibre-reinforced plastic. The diameter of each rod is reduced at one end, so that the end of a rod fits into the adjacent rod in the support. A cable of aramid or other suitable fibre is threaded

through the rods, and each end the cable is clamped to the wire of the transmitting antenna to fix the support in place and keep the rods from separating. Lower flexible portions of the antenna (4) are clamped to the upper flexible portions (2), and extend to the rigid portion (5) which forms the bottom of the antenna. The rigid bottom of the antenna is supported by rods similar to those used for the support (3). The rods at the bottom of the antenna are held together by the wire which forms the bottom part of the transmitting loop. The wire is threaded through the rods and clamped to the lower flexible portions (4). One-or-more receiving antennae (6) similar to those used in standard FL systems, which may incorporate signal-processing means, are held by support cables (7), (8) of aramid or other suitable fibre approximately 18 m from the wire of the transmitting antenna. A signal cable (9) carries the signal from the receiving antennae to signal-processing means in the helicopter. A skirt for aerodynamic drag (10) is attached to the trailing edge of the transmitting antenna.

In alternative embodiment of the invention, the transmitting antenna and ancillary components of the invention are deployed beneath a fixed-wing aircraft. For take-off and landing, the area of the antenna is collapsed by winding the flexible portions of the antenna onto winches, or other suitable controllable devices in the aircraft. Before surveying, the area of the antenna is expanded by deploying the flexible portions through ports in the belly of the aircraft, along with the receiving antennae in a bird on a separate cable.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An electromagnetic system borne by an aircraft, said system incorporating a transmitting antenna formed by one-or-more turns of wire, for which the area enclosed by said turns is able to expand during or after take-off of the aircraft, and to contract before or during landing of the aircraft.

2. A system as claimed in claim 1 in which the expansion or contraction of the area of transmitting antenna is effected by a controllable device.

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Figure 1